Exemplary Science for Building Interest in STEM Careers

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Hawker Brownlow
EDUCATION

Contents

Changes Needed in Science Education for Attracting More Students to STEM Careers

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Introduction: Robert E. Yager, Editor of ESP Monographs

Dr. Bruce Alberts served as the President for the National Academy of Sciences from 1992 to 2006. In this position he headed the efforts to produce the National Science Education Standards. He was a strong force for ensuring the inclusion of scientists in defining science and exemplifying it in their work. In addition to defining science as something all people do, Dr. Alberts was anxious that the definition also included science education and the importance of all teachers of being aware of these features and to use them in their teaching.

In 2006, Dr. Alberts became Editor-in-Chief of *Science*—the world's leading journal of original scientific research, global news, and commentary, published by the American Association for the Advancement of Science (AAAS). As editor, he has frequently offered editorial statements concerning how science education should become more inquiry-based so students are able to offer solutions to current problems. He has continued to offer personal encouragements for resolving science education problems in collaborative ways.

Dr. Alberts's editorials—Why I Became a Scientist; On Becoming a Scientist; Prioritizing Science Education; Reframing Science Standards; and An Education That Inspires—provide a "setting" for meeting Goal Four of the NSES, encouraging more students to increase their economic productivity through the use of the knowledge, understandings, and skills of the scientifically literate person.

Why I Became a Scientist

As a pre-med student at Harvard University, I took chemistry, analytical chemistry, organic chemistry, biology, physics, and so on. Although I found the content fascinating, after the first semester I could no longer tolerate the required afternoon laboratory exercise. For two and a half years, I had spent two or three afternoons each week performing tedious cookbook exercises:

Measure this, measure that, get an answer and compare it with all the answers your friends got, fudge the data so that you get the right answer, and then turn in your notebook. (Amazingly, the same boring laboratory exercises continue at most of our universities today, nearly 50 years later!)

I finally found the courage to complain: "I love physical chemistry, but I hate this laboratory. What can I do?" My professors told me that if I joined a research laboratory for a semester, I wouldn't have to take the physical chemistry laboratory. So that spring I worked in Professor Paul Doty's laboratory. This was completely different from the afternoon course laboratories. I discovered the excitement of science, and I forgot about medical school (2006/2007).

On Becoming a Scientist

One normally becomes a scientist through a series of apprenticeships, pursuing research in laboratories directed by established scientists. My own scientific mentors were Jacques Fresco and Paul Doty at Harvard, where I learned not only technical skills but also how to think and function as a scientist. Both from them and by making my own mistakes, I learned how to identify important problems, how to think critically, and how to design effective research strategies (2004). Because so much of one's scientific future is shaped by early experiences, it is critical that beginning scientists select their mentors wisely. Unfortunately, what constitutes a "good" choice is not always obvious. Here I offer some personal advice to help young scientists make these tough decisions wisely.

The exact project pursued for a PhD degree is not nearly as important as finding the best place for learning how to push forward the frontier of knowledge as an independent investigator. My first piece of advice for graduate students is to begin research training in a laboratory led by a person with high scientific and ethical standards. It is by talking to people in that lab or those who have previously trained there, and by consulting other scientists in the same field, that one can gain this important insight.

It is also important to find an adviser who will pay close attention to your development as a scientist. Brilliant scientists sometimes make poor mentors. Often, an established leader who has no more than about a dozen people to manage can best nurture a creative, exciting, and supportive place to work. But carrying out research with an outstanding new professor with a very small group can frequently provide even better training.

Students enter graduate school both to learn how to do science well and to discover where their talents and interests lie. Success at either task requires that they be empowered to create new approaches and to generate new ideas. In my experience, beginning scientists will only gain the confidence needed to confront the unknown successfully by making discoveries through experiments of their own design. The best research advisers will therefore provide their graduate students with enough guidance to prevent them from wasting time on nonproductive pursuits, while giving them the freedom to innovate and to learn from their own mistakes.

In my field of biology, two apprenticeships are standard for beginning scientists; first while earning a PhD degree and then in a second laboratory in a postdoctoral position. The choice of a postdoctoral laboratory is best made with a long-term career plan in mind. Scientists at this stage should intentionally try to choose a laboratory where they can acquire skills that complement those they already have. For example, a student whose PhD thesis gave her strong skills as a yeast geneticist might choose to do postdoctoral research with an expert protein biochemist, planning to use a combination of powerful genetic and biochemical tools to attack a biological problem in an area where very few scientists have the same abilities.

But success as an independent scientist will require much more than technical skills. It is critical to be able to design research strategies that are ambitious enough to be important and exciting, innovative enough to make unique contributions likely, and nevertheless have a good chance of producing valuable results. An enormous number of different experiments are possible, but only a tiny proportion will be really worthwhile. Choosing well requires great thought and creativity, and it involves taking risks (2009).

Prioritizing Science Education

We will focus on the connection between learning science in school and the acquisition of language and communication skills, emphasizing the benefits of teaching science and literacy in the same classrooms whenever possible. In the United States, this would be viewed as a radical proposal. Unfortunately, the great majority of Americans are accustomed to science classrooms where students memorize facts about the natural world and, if they are lucky, perform an experiment or two; in language arts classes, students generally read fictional literature and write about it in fossilized formats such as "compare and contrast."

The exciting news is that "science learning entails and benefits from embedded literacy activities [and]…literacy learning entails and benefits from being embedded within science inquiry" (Pearson, Moje, and Greenleaf 2010). Here, it is helpful to distinguish between factual (or informational) and fictional (or narrative) text. Science reading and writing is largely of the former type, and it is this factual, informational text that dominates today's knowledge-everywhere world. Yet, most of the formal teaching in language arts classrooms deals with fictional text. My own failed efforts at storytelling lacked the imagination to do anything more than rewrite Hansel and Gretel in a thinly disguised new context. Without doubt, learning to write and read clear and concise informational text, as in summaries of investigations in science class, is an essential preparation for nearly all of life out of school.

Reconceptualizing science education by closely connecting literacy lessons with active inquiry learning in science class allows one to make a strong argument for greatly expanding the time spent on science in primary school to at least four hours a week. This alone would carry tremendous benefits in places—like the United States—where science has often become marginalized to less than an hour a week.

A second advantage to forging this connection between literacy and science teaching is that a well-taught science class gives everyone a chance to excel at something. It is hard to stay motivated and interested in schooling if one is always in the bottom half of the class. By linking literacy and science education, those who are more challenged with making progress in reading can gain the self-confidence needed to succeed by demonstrating skills in analyzing a problem that stumps the better readers. Or they might excel in the mechanical manipulation of objects required in a science lesson. From this perspective, the penalties for "failing" schools in my home state of California are tragically wrong: Students who struggle with reading or math are given double periods of reading or math drill, and the very set of activities that could excite them about school is eliminated.

I am reminded of the schooling of P. Roy Vagelos, an outstanding scientific leader in U.S. academia and industry. A fellow biochemist and a friend, Roy topped off his career by becoming the chief executive officer of the major pharmaceutical company Merck, with *Fortune* magazine anointing his company as the "most admired in America" for seven successive years (1987–1993). In his biography, he describes himself as a poor memorizer, who nearly failed first and second grade and was largely alienated from school until he was given the chance to demonstrate other skills that allowed him to excel (Vagelos and Galambos 2004).

How many talented young people are we losing in today's schools, driven by test scores that reward teachers for drilling students to remember obscure science words, and by an early reading curriculum based on stories and folk tales? Instead, we should be rewarding teachers for teaching science inquiry skills and literacy together, through collaborative and critical discourse (Osborne 2010; Alberts 2010).

Reframing Science Standards

A promising draft *Framework for Science Education* was posted by the National Academies for public comment and review. Its goal is to define the science that all students should be taught from age 5 through precollege in the United States, building on lessons learned from the 1996 National Science Education Standards (NSES). Will this new effort, initiated to help produce a common core for science education across states (Leshner, Malcom, and Roseman 2010) be more successful than the last one?

In 1989, the governors of all 50 states issued a call for "voluntary national standards" in each of the major academic disciplines. In response, the NSES were issued by the National Academies of Sciences in 1996. The results have been disappointing. In particular, the requirement for students to master a large number of facts and concepts took precedence over the strong emphasis on "science as inquiry" in the NSES. The new *Framework* attempts to overcome this problem in several interesting ways.

First, the *Framework* focuses on only four core concepts in each of four disciplines: life sciences, physical science, Earth and space sciences, and engineering and technology. And differing from the NSES, each core concept extends over all years of schooling. The intention is to leave room during the school day for three important strands of science learning that have been systematically ignored in favor of the traditional content strand, which focuses on knowing, using and interpreting scientific explanations of the natural world. The critical strands that have been missing are (1) generating and evaluating scientific evidence and explanations, (2) understanding the nature and development of scientific knowledge, and (3) participating in scientific practices and discourse (Alberts 2009).

Second, the *Framework* supplements the dominant theme of inquiry in the NSES with a greatly expanded discussion of why any definition of science education must center around active participation in scientific practices and extensive experience with evaluating evidence. The current focus on transmitting only the knowledge that scientists have discovered fails to provide students with the thinking and problem-solving skills that are essential for life in our complex societies, and it also fails to give them a sound understanding of why science has been so successful as a special way of knowing about the world. Thus, the *Framework* contains a powerful chapter with 16 useful tables entitled Scientific and Engineering Practices. (The inclusion of engineering itself represents a major, positive break with tradition.)

The *Framework* also stresses the importance of building coherence into the science curriculum from year to year through reference to the ongoing research on "learning progressions." As an example, the recognition that any object is composed of specific materials, and has certain properties because of those materials, is known to be an important first step toward understanding atomic-molecular theory. To guide curriculum design, the last half of the document presents prototype learning progressions for each of the core concepts to be learned, expanding on the landmark *Atlas for Science Literacy* produced by the American Association for the Advancement of Science.

The Framework was finalized in response to the feedback received on the public draft, and then, because responsibility for education is assigned to each state by the U.S. Constitution, the final standards are being developed through a coalition of states led by the nonprofit organization Achieve. The worst thing that scientists could do would be to insist that the core disciplinary ideas be expanded to include their specialties. Instead, the scientific community should focus on preparing college students to "ask questions; collect, analyze, and interpret data; construct and critique arguments; communicate and interpret scientific and technical tests; and apply and use scientific knowledge"—precisely as the *Framework* specifies for the precollege years (Alberts 2010).

An Education That Inspires

Why is it that children, who enter school at age five, filled with excitement and wonder about the world, often become bored with education before their teenage years? How might the United States produce a more engaging education system, one that allows a child with a specific fascination to explore that interest in depth as an integral part of his or her early education? Here I sketch a possible plan based on science, technology, engineering, and math (STEM) awards that would be largely earned through student activities outside of school.

The idea has been partly inspired by the U.S. Advanced Placement (AP) system of courses and exams, which makes a first-year college-level education in selected subjects available to high school students. As a nationally recognized standard of achievement, passing an AP course is a mark of success for both students and schools. High schools now strive to increase the number of students taking such courses, and this nongovernmental but nationally certified program has been rapidly growing in popularity. Could a nationally validated set of "STEM challenge awards," designed for students at earlier stages of schooling, similarly motivate schools and school systems to value a new type of achievement?

I suggest that the proposed STEM challenge awards be modeled on the achievement badges that youth organizations around the world have developed to promote the active learning of specific subjects in depth. For example, the Boy Scouts of America allows more than 100 different merit badges to be earned, each focused on a specific topic such as plant science or lifesaving.*
In addition to this large selection, each badge provides a young person with a variety of options. Thus, to earn a plant science merit badge, a scout can choose between agronomy, horticulture, or field botany. Most learning experiences are active ones, such as "Select a study site that is at least

* *www.scouting.org/scoutsource/BoyScouts/AdvancementandAwards/MeritBadges.aspx*

100 × 100 ft. Make a list of the plants in the study site by groups of plants: canopy trees, small trees, shrubs, herbaceous wildflowers and grasses, vines, ferns, mosses, algae, fungi, lichens. Find out which are native plants and which are exotic (or nonnative).” This is infinitely more interesting than a typical school experience in which students memorize the names of plants and their parts from pictures in a textbook, often without encountering the actual object.

A STEM challenge award program might provide 100 different challenges to choose from at each level of schooling (for example, sets of awards of increasing difficulty for ages 5–8, 9–13, and 14–18), on subjects ranging from reptiles to website design. Scientific and engineering societies in each discipline could create the requirements for many awards, as could industry groups or government agencies such as the U.S. National Aeronautics and Space Agency. But a single umbrella organization would be needed to certify the contents of the award projects, as well as the mechanisms used to judge and record their completion. Such national certification would be critical for the awards to have a substantial positive impact, serving as a widely recognized, valid mark of success for both students and school districts.

The most ambitious and revolutionary part of this plan supplements the teachers in schools with adult volunteers, each serving as an expert for a particular STEM challenge award. To earn a merit badge, a scout must demonstrate to a qualified adult volunteer (a “counselor” for that badge) that he has satisfied that badge’s requirements. In a similar way, many thousands of adults with science and technology backgrounds would be enlisted as counselors, both to help teachers and to judge each student’s performance, making full use of modern communications tools. A great many scientists and engineers would be willing to contribute to improving science in schools if an efficient and effective way for them to do so could be generated. And their contributions could truly inspire today’s students (Alberts 2010).

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